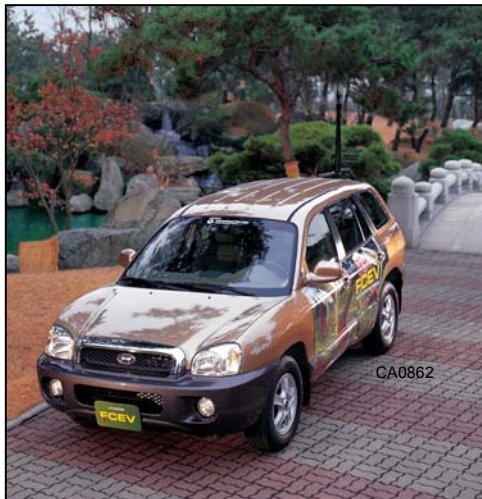




UTC Fuel Cells

A United Technologies Company



PEM Fuel Cell Air Blowers DOE Merit Review

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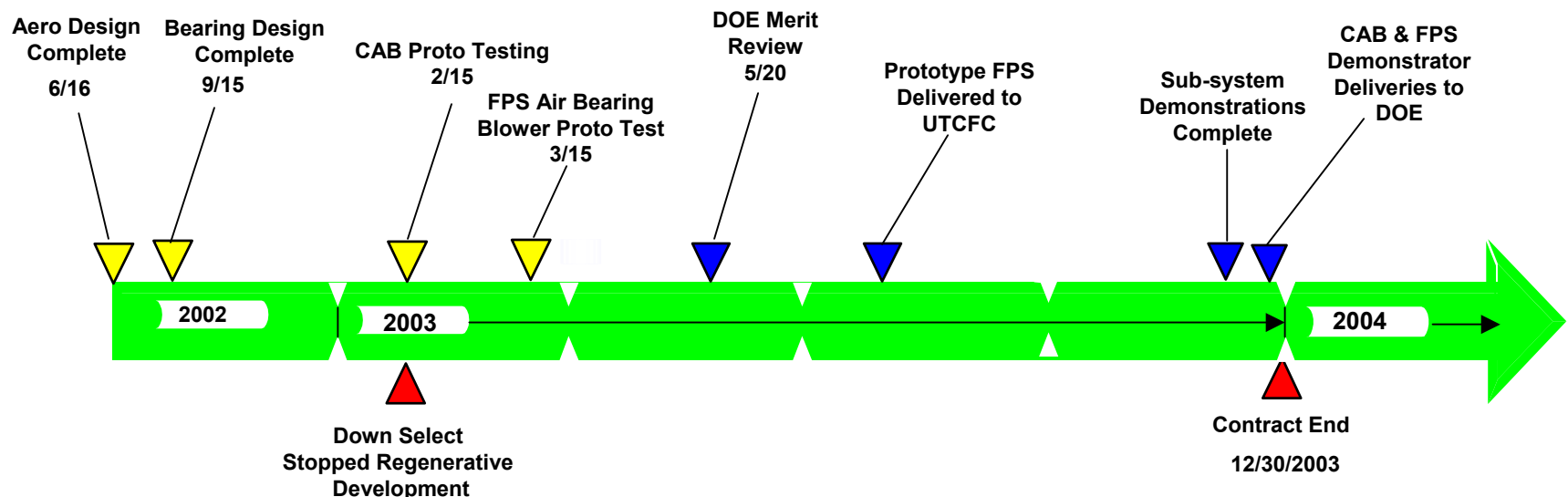
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Program Objectives / Schedule

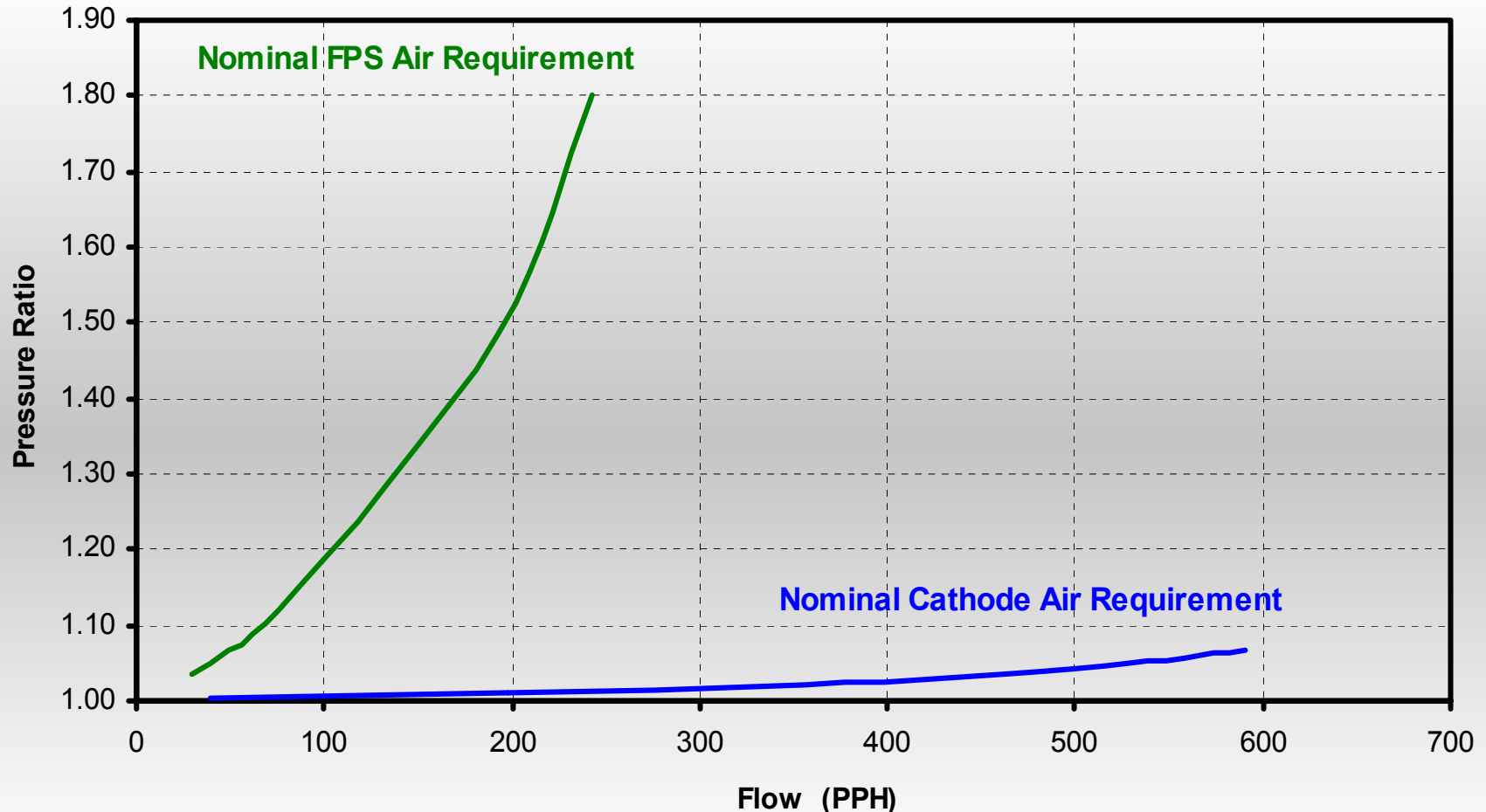
1. Develop a blower technology base for ambient fuel cells
2. Reduce weight and cost
3. Increase Performance
4. Improve Reliability
5. Develop a supplier base



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Ambient Pressure Fuel Cell Blower Performance Requirements
75 kW Power Plant

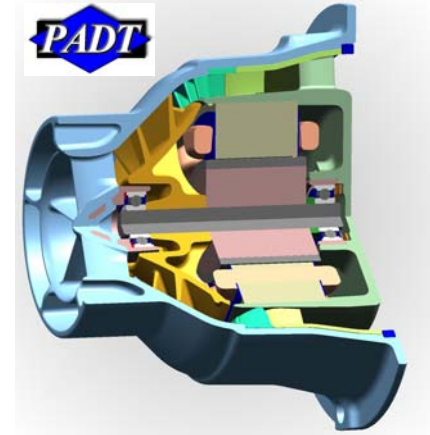


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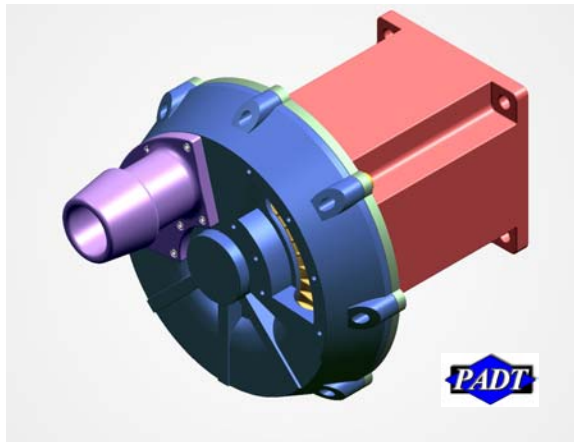
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Three Blowers Being Developed by Two Subcontractors

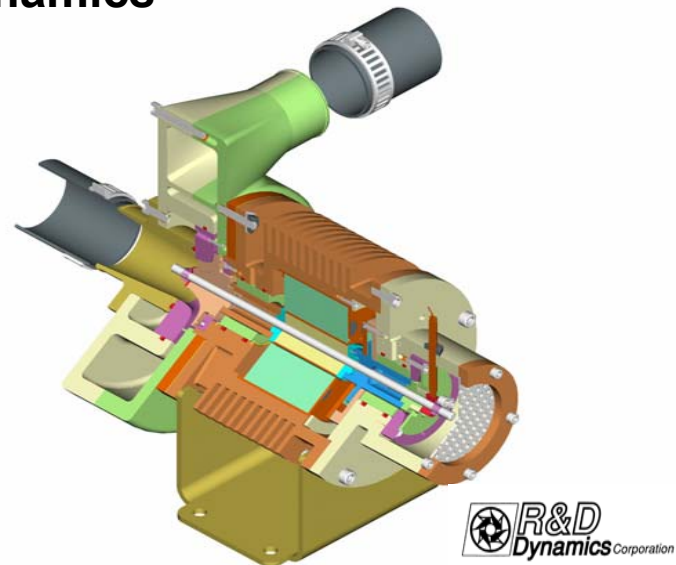
1. Vane Axial Cathode Air Blower, PADT
2. Regenerative FPS Air Blower, PADT
3. Centrifugal FPS Air Blower, R&D Dynamics



CAB Vane Axial



FPS Regenerative



FPS Centrifugal

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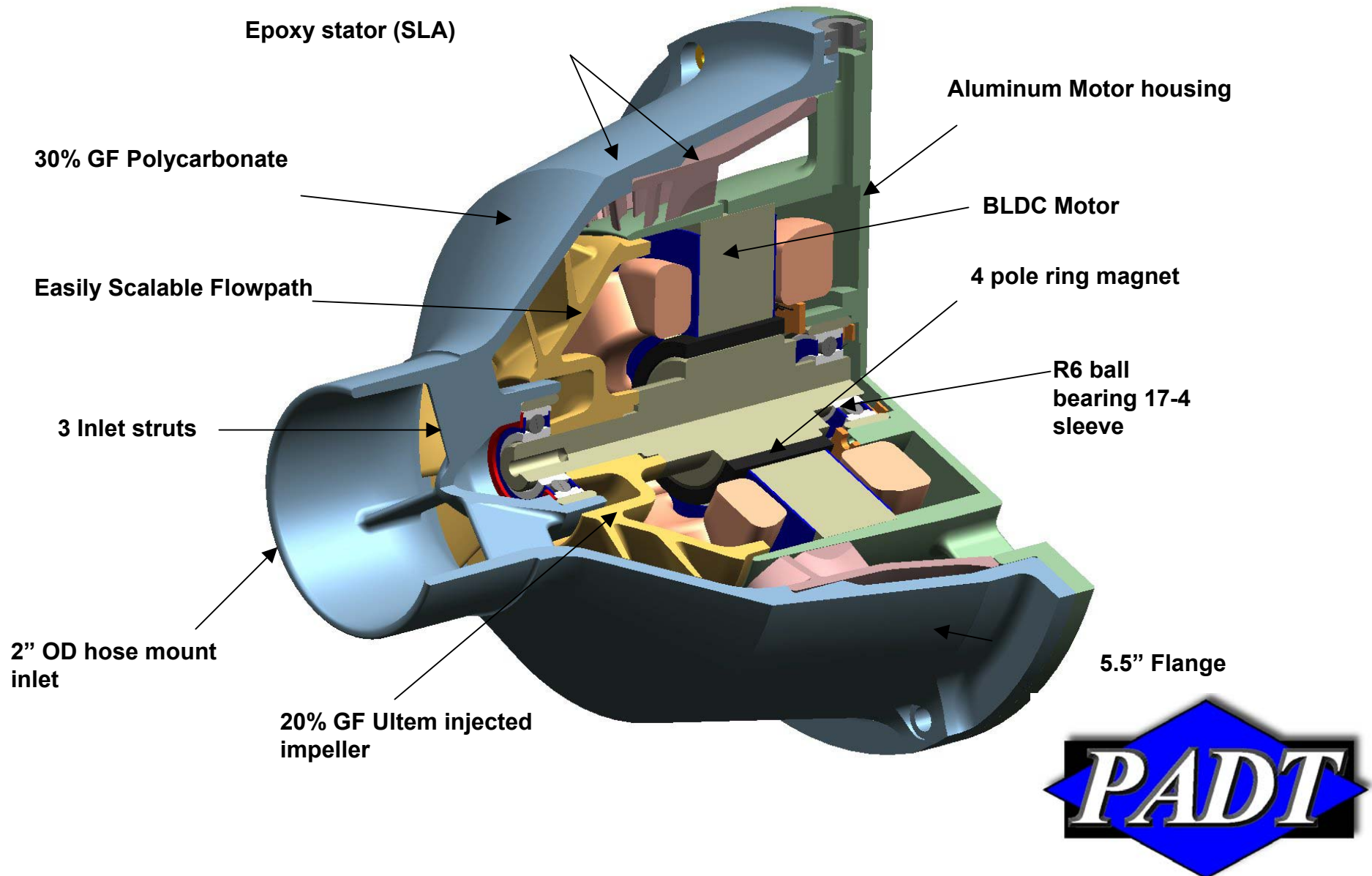
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Cathode Air Blower Goals

- Performance: 1 psi @ 170 cfm
- Design for low cost < \$75 at 100K units / year
- Demonstrate overall efficiency > 60%
- Design for 5000 hour service life
- Design blower that is easily scalable in flow
- Deliver hardware for Q4 2003 DOE P/P demonstration

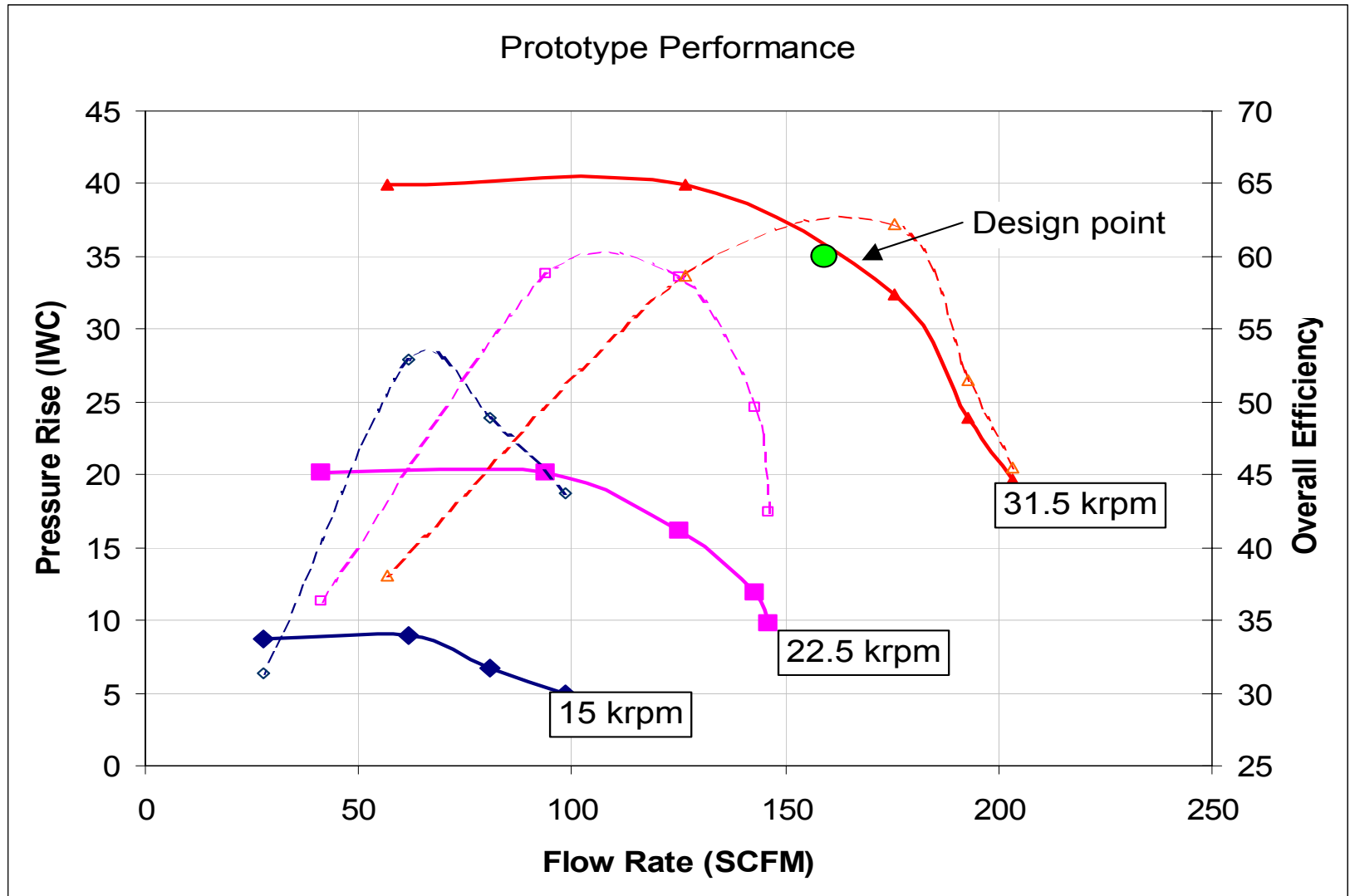
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Prototype *Exceeds* Efficiency Target

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Cathode Air Blower Status

- Design Features
 - Achieved compact integrated design
 - Selected mixed flow axial machine
 - Motor cooled by process fluid
 - Designed for manufacturability
 - Utilization of injection molded parts
- Technical Accomplishments
 - Prototype blower meets flow and pressure specifications
 - Custom motor and controller meets performance expectations
 - Resolved motor rotor heating by increasing switching frequency to 80 kHz
 - High volume configuration optimization underway
 - Volume quoted cost projection: \$83.95
 - Remaining work emphasizes cost reduction and increasing robustness

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Remaining CAB Technology Tasks

- Finalize blower design for high volume mfg.
 - Continued manufacturing cost analysis
 - Plastic over-mold motor housing test
 - Evaluate effects of thermally potted motor winding
 - Bearing liner overmold test
- Finalize blower detailed design for low-cost / initial volume mfg, make and test prototypes
- Complete blower durability / reliability testing
 - Bearing life, shock & vibration, creep, high temperature testing
- Develop and implement sensor-less motor controls into controller and redesign for low cost.

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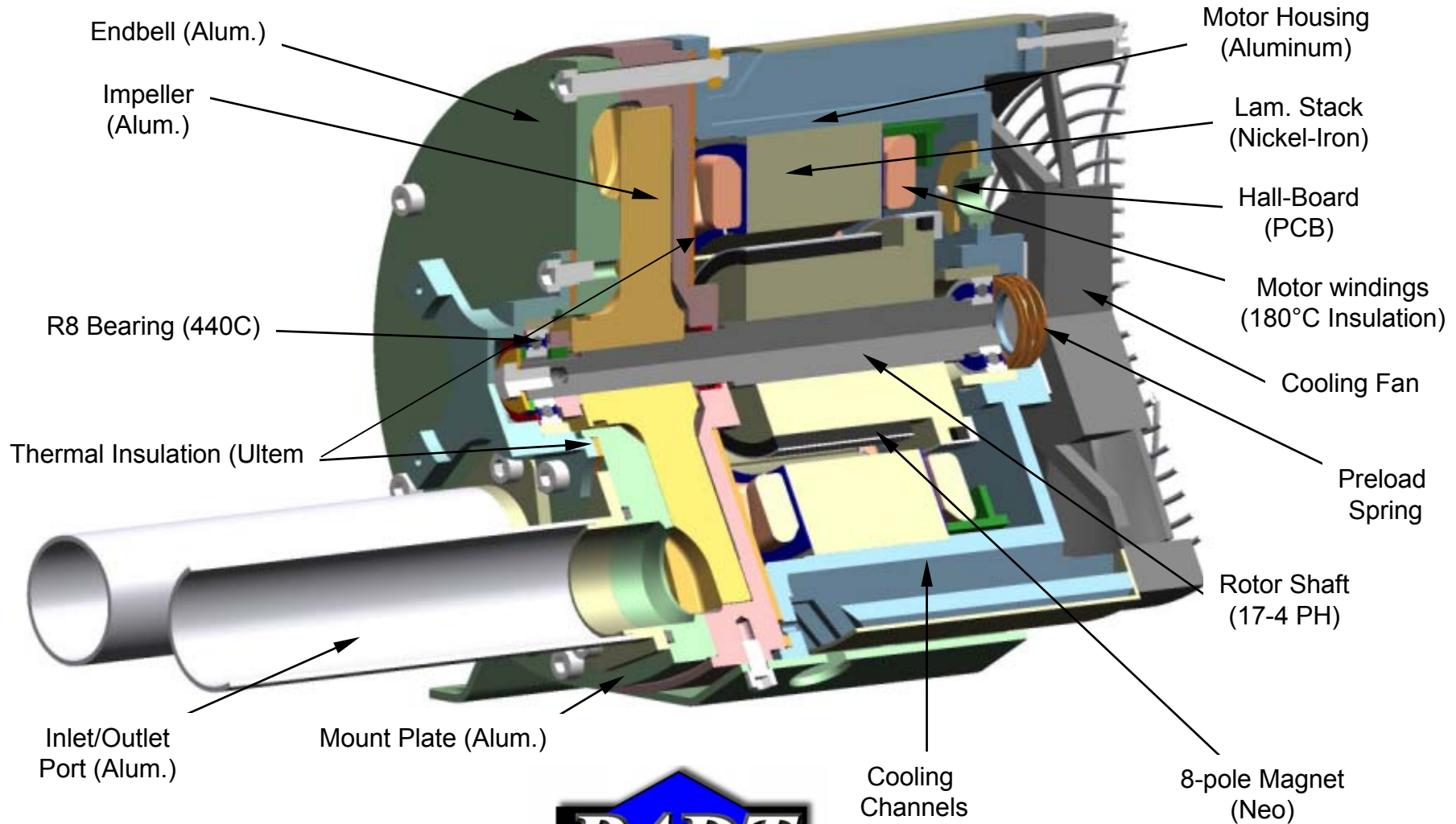
FPS Blower Goals

- Performance: 12 psi @ 70 cfm
- Design for low cost < \$75 at 100K units / year
- Demonstrate overall efficiency > 50%
- Weight: 10 lbs (includes controller)
- Design for 5000 hour service life
- Develop novel regenerative blower technology that provides higher efficiency
- Deliver hardware for Q4 2003 DOE P/P demonstration

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Regenerative FPS Blower



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PADT FPS Regenerative Blower Project Status

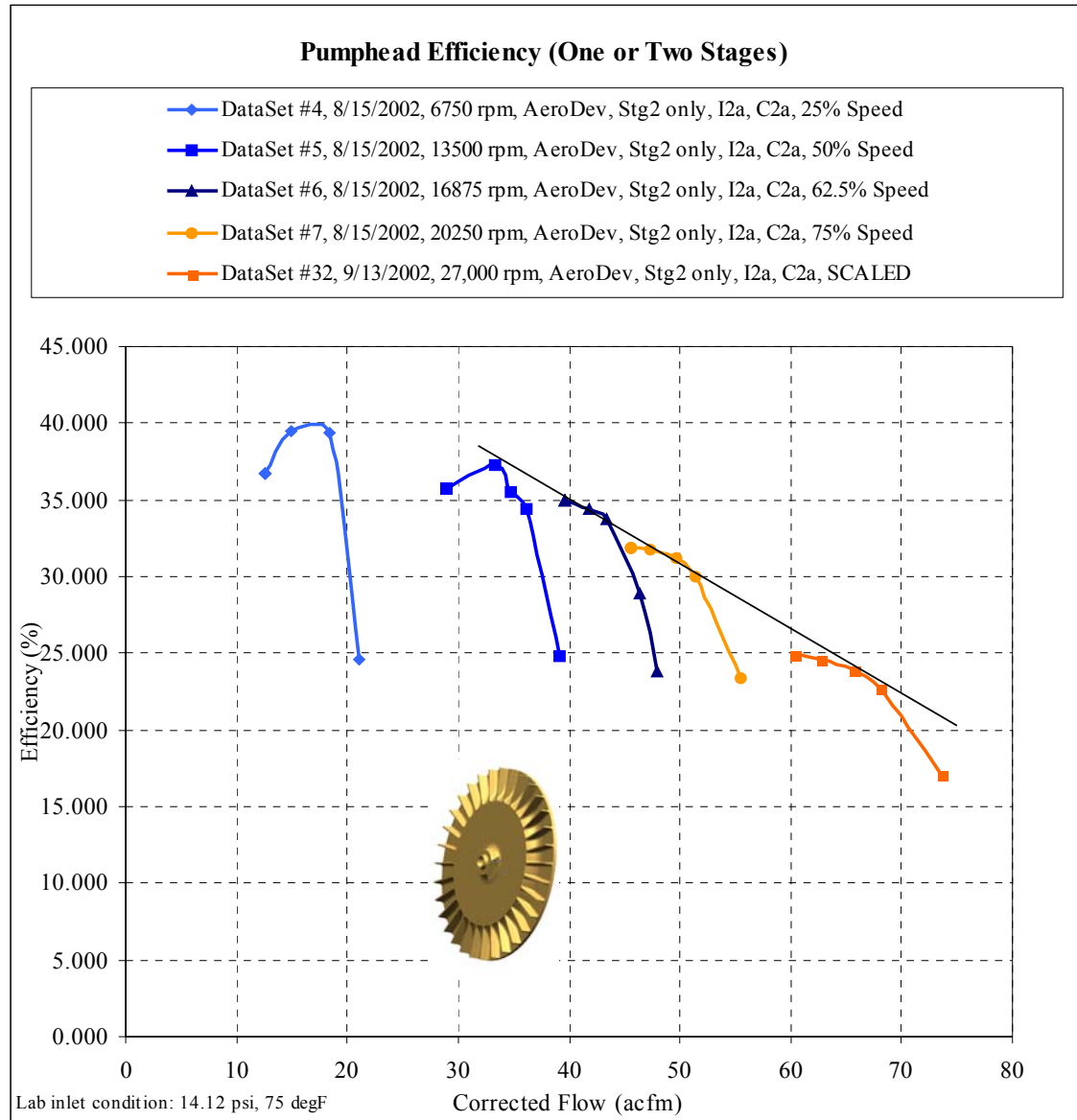
- Extensive CFD work and testing has indicated **low efficiencies**
- Low aerodynamic efficiency compounds motor heating problem
- 2 stage approach was evaluated but was large, expensive and resulted in thermal growth issues
- Remaining work will entail aerodynamic testing of promising geometries

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Aero Efficiencies are Low

- Regen. was chosen because it builds good pressure at low flow with lower RPM
- However, regens are inherently low in efficiency
- Carry over is main efficiency culprit which especially at high pressure ratios
- Motor rotor heating may also contribute to trend
- Test matrix underway with SLS hardware to establish peak efficiency



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Regenerative Blower Technical Lessons Learned

- Regenerative air blowers are most efficient at low pressure ratios, < 1.3
- Significant performance losses are incurred due to carry-over of preworked air from outlet to inlet.
- Exit to inlet port leakage impacts efficiency and elevates inlet air temperature
- Two stage regenerative approaches should be avoided.
 - Relative growth between stage 1 and stage 2 lead to large clearances and poor performance.
 - Transferring air from one stage to the next was very inefficient
 - Sealing between the stages was very difficult.
- Low pump head efficiencies lead to high motor heat rejection
- RPM reduction with a regenerative approach is \sim factor of 4 over centrifugal approach. However efficiency is approx. $\frac{1}{2}$ of a centrifugal machine.

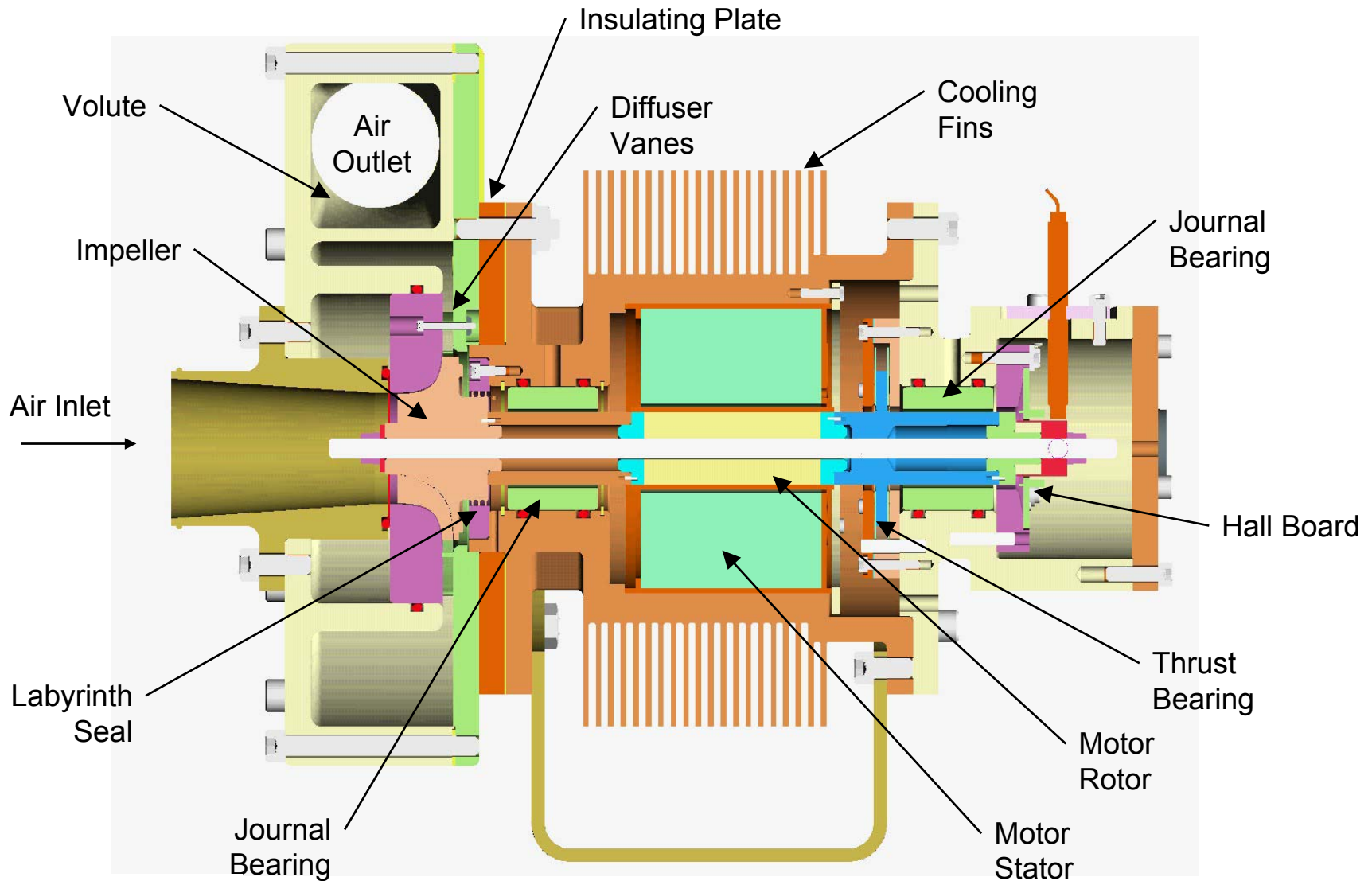
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Regenerative Blower Down-select

- The regenerative approach is too inefficient for this particular specification
- CFD results did lead to modest improvements (3-5%) on paper. 6 sets of SLS hardware have been produced to explore the expected trends
- Test final set of SLS hardware and issue summary report
- Results of this work could be used in other fuel cell applications that are well suited to regenerative compressors. Hydrogen Recycle and Moderate pressure Cathode air deliveries are potential applications

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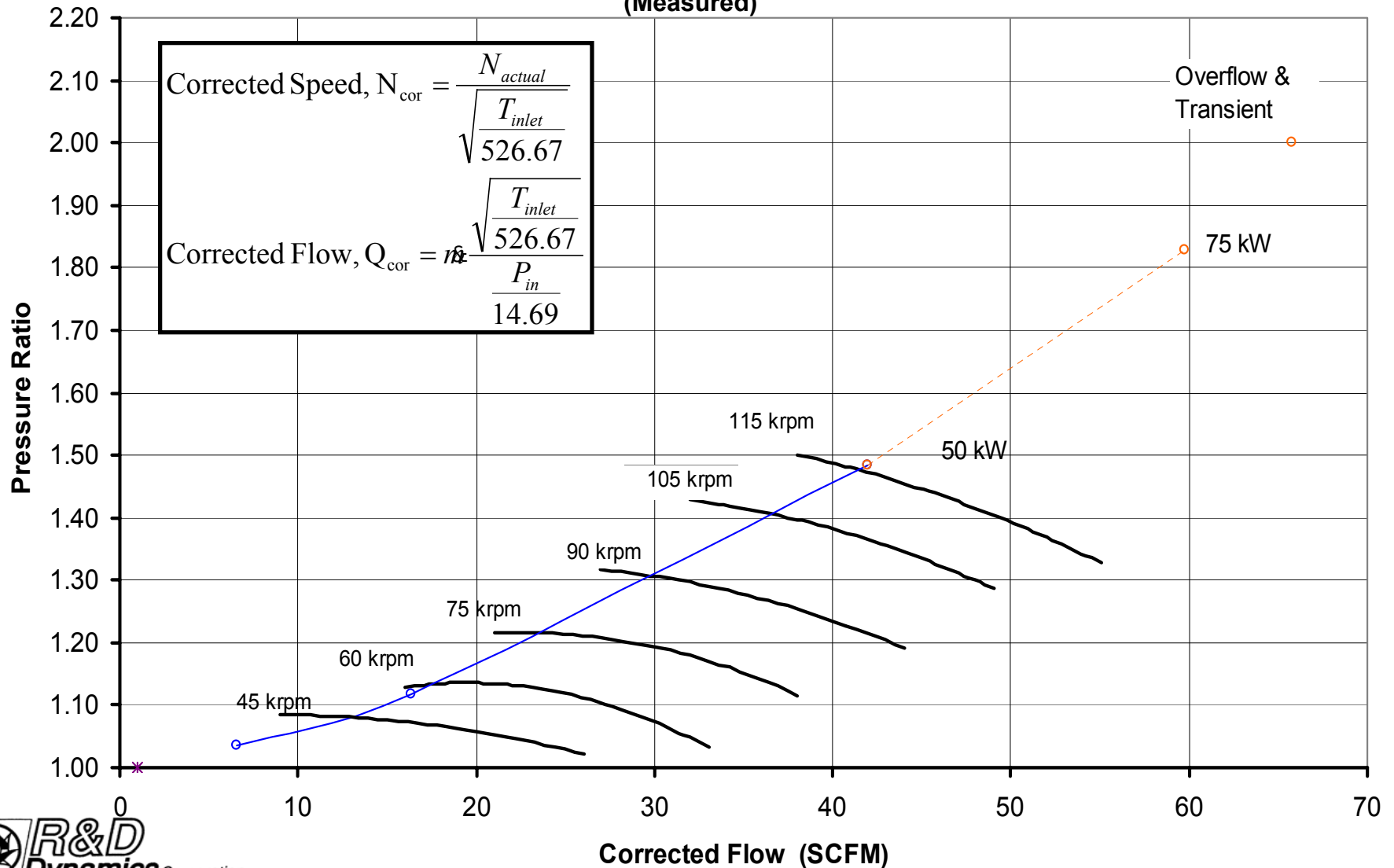


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FPS Blower Performance

(Measured)



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FPS Centrifugal Air Blower Status

- Design Features
 - High speed centrifugal design, 140K rpm
 - Utilizes foil air bearing technology
 - Motor and controller air cooled
 - Total Weight 30 lbs
- Project Accomplishments
 - Foil air bearings and rotating group tested to 153 Krpm
 - Aerodynamic performance and controller verified to 108,000 rpm, performance meets predictions
 - Blower / controller cost projection, in volume: \$163
- Technical Issue
 - Heat buildup demagnetizes motor rotor

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FPS Blower

Rotating Assembly



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R&D Dynamics FPS Blower, Remaining Tasks

- Demonstrate blower with new motor and controller
 - New motor designed to minimize rotor heating and eddy current losses via laminated rotor magnet and proprietary rotor magnet sleeve
- Incorporate improved rotor cooling scheme
- Performance test to full speed
- Complete blower durability / reliability testing
 - Bearing life, shock & vibration, creep, high temperature testing
- Refine and finalize manufacturing cost estimates
- Evaluate and mitigate acoustic noise